Primary-Context Model and Ontology: A Combined Approach for Pervasive Transportation Services

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Abstract

Advanced pervasive transportation services aim to improve the safety and efficiency of public and private transportation facilities, while reducing operating costs and improving the travel experience for drivers, passengers and other travellers. In order to achieve these goals, such services require access to context information from a myriad of distributed, heterogeneous Intelligent Transportation Systems. A context management scheme that models information in a standard fashion is essential to support information sharing between individual systems, and higher-level information reasoning. This paper presents an ontology-based spatial context model, which takes a combined approach to modelling context information utilised by pervasive transportation services: the Primary-Context Model facilitates interoperation across independent Intelligent Transportation Systems, whereas the Primary-Context Ontology enables pervasive transportation services to reason about shared context information and to react accordingly. The independently defined, distributed information is correlated based on its primary-context: location, time, identity, and quality of service. The Primary-Context Model and Ontology have been evaluated by modelling a car park system for a smart parking space locator service.

I. Introduction

As transport networks become more congested, there is a growing need to adopt policies that manage demand and make full use of existing assets. Advances in information technology are now such that Intelligent Transportation Systems (ITS) offer real possibilities for authorities to meet this challenge: by monitoring the current status of an environment, predicting what might happen in the future, and providing the means to manage transport proactively and on an area-wide basis [1]. For example traffic flow monitoring can reduce areas of traffic congestion, or electronic toll collection can reduce delay at toll-booths. Key to achieving a reliable, well-managed transportation network is the provision of real-time, distributed, pervasive transportation services that dynamically merge context-information from autonomous ITS.

ITS architectures, such as the iTransIT framework [2], aim to provide a structured approach for designing and implementing ITS, so as to ensure their interoperability and the compatibility of their traffic data sets. Essential to such architectures is a context model that consistently captures, manages, and stores distributed information in a dynamic and scalable manner. iTransIT proposes the object-based spatial programming model for this purpose. But this model lacks a way to explicitly represent the semantics of context information, e.g. that both a train and a tram are public vehicles, or that a motorway consists of two lanes going in each direction.

This paper presents the Primary-Context Model and Ontology (PCM and PCOnt), an ontology-based spatial context model based on the iTransIT Framework. We adopt a combined approach to modelling context information [3], incorporating the management and communication benefits of traditional context-modelling, and the semantic and inference benefits of ontologies. Primary-context refers to location, time, identity, and quality of service context. Its role in context management is the indexing of context information, so that it can be stored and accessed efficiently [3]. Our model extends this idea by using primary-context to correlate and manage context data appropriately.

An ontology contains a thorough representation of knowledge for a particular knowledge domain. The PCOnt has been designed with a special focus on the transportation domain in order to assume its real-world applicability. However, we envisage that the proposed PCM/PCOnt approach can be applied to other domains as well.

The remainder of this paper is structured as follows: Section II examines related context-modelling approaches. Section III introduces the iTransIT framework for integrating individual transportation systems and related user services. Section IV describes the PCM and PCOnt, and how they facilitate the integration of ITS. Section IV presents an assessment of this work and, finally, section VI concludes by summarising our work.

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II. Related Work

Recent context-aware research has focused on toolkits and infrastructures that decouple context-aware applications from sensor devices. Early work, including Georgia Tech's Context Toolkit [4], was designed with a specific domain in mind, e.g. a business meeting room, a smart house. Moreover, they did not provide a mechanism that allowed for reasoning about the context information.

The next generation of projects, such as the GAIA project [5], used ontologies to meet this challenge. However, they offered limited scalability and domain-specific ontologies, written in languages with minimal reasoning capabilities: RDF and DAML+OIL. The Nexus platform [6] is a large-scale, pervasive computing system that integrates local context-models from different providers into an object-based, federated model. An object-based model does not offer the same advantages as one based on an ontology; such as information sharing, a common-understanding of terms, and reasoning. Both Chen and Finin [7], and Gu et al. [8] suggest a two-layer hierarchical approach written in the Web Ontology Language (OWL). They define upper-level ontologies to describe general context-information, and domain-specific ontologies to provide additional vocabularies for supporting specific types of applications.

The DAIDALOS project [9] proposes a combined location-based context-model and generic context-ontology approach, based on [3], with the aim of integrating the advantages of both approaches, while achieving maximum scalability, efficient reasoning, and context interpretation in large-scale, distributed, context-aware systems. In this paper we adopt a similar hybrid approach, combining the PCM with the PCOnt. However, in DAIDALOS, the proposed context-model is based on semantic context entities, their attributes, and their associations with other entities. The spatial context-model presented here is more specific than the generic DAIDALOS context model, and it enables information to be correlated based on its primary-context.

III. iTransIT Architecture Overview

As illustrated in Figure 1, the iTransIT architecture structures legacy systems, iTransIT systems, and context-aware, end-user applications into three tiers. These tiers define the relationships between systems and applications, and provide a scalable approach for integrating systems, in that individual components can be added to a specific tier without direct consequences to the components in the remaining tiers.

A. Tier Architecture

The legacy tier provides for the integration of legacy systems and describes existing transportation systems, as well as future ones that have not been developed to conform to the iTransIT system architecture and data layer.

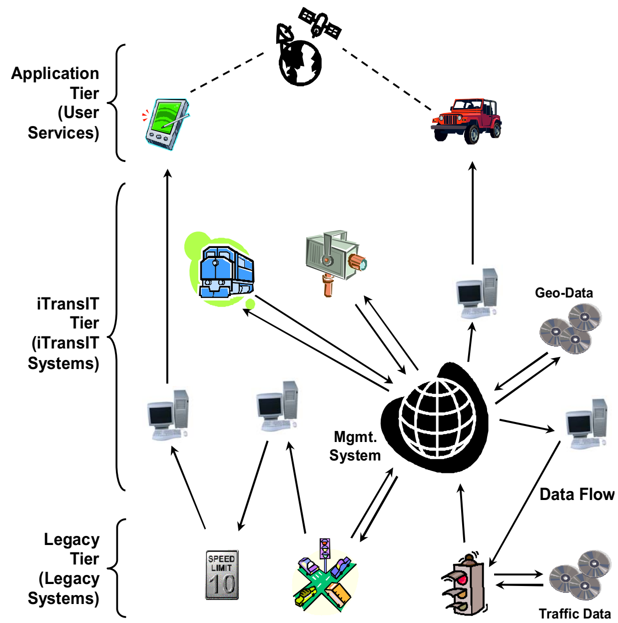

Figure 1. iTransIT ITS framework overview

The purpose of the iTransIT tier is to integrate transportation systems that model spatial information and implement the Spatial Application Programming Interface (Spatial API) [10]. Therefore, this tier comprises of a federation of transportation systems that implement the spatial data layer. The data layer is distributed across these iTransIT systems, with each system implementing the subset of the overall layer that is relevant to its operation. iTransIT systems maintain their individual information, which is often gathered by sensors or provided to actuators, by populating the relevant part of the spatial data layer. However, some of the information maintained in an iTransIT system specific part of the data layer may actually be provided by underlying legacy systems. Most significantly, traffic information captured in this tier is maintained with its primary-context, and persistently stored data is geo-coded typically by systems exploiting a database with spatial extensions.

The application tier includes pervasive value added services that provide context-aware user access to traffic information. These services use the distributed data layer and associated context to access information potentially provided by multiple systems. They could include a wide range of interactive (Internet-based) and embedded

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control services, ranging from the monitoring of live and historical traffic information to the display of road network maps.

B. Common Spatial Data Layer

The spatial data layer, common to all iTransIT systems, is comprised of a set of potentially distributed sub-layers and represents the central component of these systems. Individual iTransIT systems implement one or more of these sub-layers (or parts of sub-layers) and maintain the static, dynamic, live, or historical traffic data available in that sub-layer. For example, a system might implement a sub-layer describing the current weather conditions, while another sub-layer capturing intersection-based traffic volumes might be maintained by a different system.

IV. Primary-Context Model and Ontology

ITS typically operate in highly dynamic environments with a large number of users and requests. The PCM provides a standard way for iTransIT systems to store, manage and share distributed information in a scalable manner, based on its primary-context. Pervasive transportation services may access this information using a common interface, the Spatial API. The PCOnt formally specifies the concepts that may be referred to by the PCM, and the relationships that hold between these concepts. A thorough representation of all domain knowledge is provided, which can then be used to reason about context information. All information captured in the iTransIT common spatial data layer is uniformly modelled using the PCM and is associated with a type defined by the PCOnt. The semantic meaning of information is derived from these types and how the types relate to each other.

A. Primary-Context Model

The PCM models all information according to primary-context, allowing for cross-system correlation and querying. For example, a pervasive transportation service may submit a query to the iTransIT architecture, using the spatial API, requesting entities at a certain location that produce data within a particular timeframe. The object-based PCM is shown in Figure 2. The root object of the PCM is a spatial object, which represents any entity in our environment. All spatial objects must be associated with an identity primary-context object. This classifies the type of the spatial object and its identifier (ID). Types will be discussed in detail in subsection B. An ID is exclusive within a certain type, so that the combination of both type and ID uniquely identifies an object in the iTransIT architecture. At least one name must also be affiliated with the object and a description may be added, if desired, to facilitate human-readable queries. Spatial objects also have a set of parameters associated with them, describing the modelled transportation information.

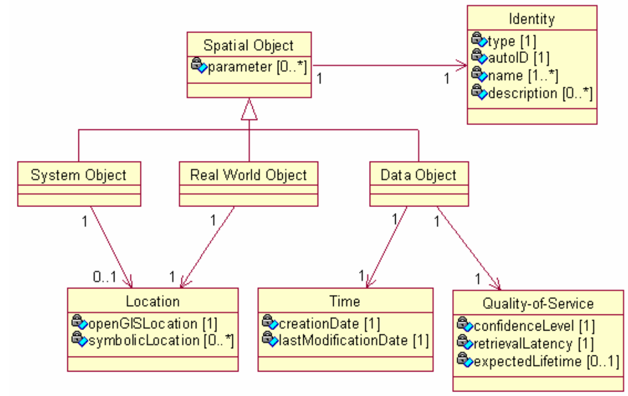

Figure 2. Primary-Context Model (PCM)

The PCM defines three different kinds of spatial objects: the system object, the real world object and the data object. They all inherit the properties of a spatial object, i.e. they must be associated with an identity primary-context object and they have a set of parameters. System objects are used to model ITS along with their associated attributes, such as operational status or parent organisation. Examples of system objects might include a car parking system, a road weather system or a journey time estimator system. Real world objects represent physical entities in the environment, for instance vehicles, barometers, detector loops or traffic lights. Data objects model static or dynamic information regarding, or generated by, ITS, such as bus timetables or the number of available car parking spaces. The common spatial data layer is modelled using combinations of these objects, resulting in a homogenous representation of all information, which can be accessed using the Spatial API.

Whereas real world objects must be associated with a location primary-context object, system objects may or may not be. A location primary-context object defines a particular topographical position, where a real world object currently resides, or a topographical area to which a system object applies. Unlike topological approaches, in which geographical relationships between spatial objects are described explicitly, topographical models define relationships between spatial objects implicitly. This enables location primary-context objects to be defined autonomously by distributed iTransIT systems, without global knowledge of other existing objects. Pervasive transportation services can exploit this approach by querying for data based on topographical location and correlating the results.

Spatial context-information is modelled as a geometric shape, according to the OpenGIS standard, and defined by a sequence of coordinates based on a chosen, well-known coordinate system. As well as the geographic representation of a location, a symbolic description of a location may also be given. This allows for human-readable queries and replies. For example, a polygon of coordinates may also be described by its symbolic location, namely: Stephens Green Park.

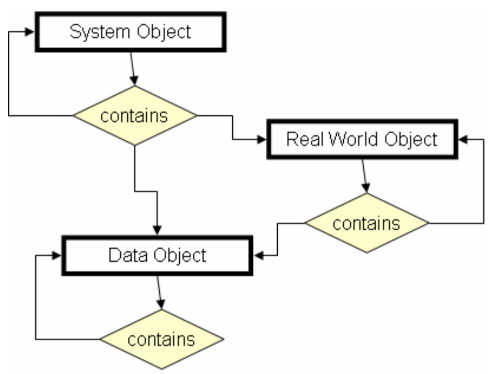

Figure 3. Combining Spatial Objects

Both time and quality of service primary-context objects must be associated with a data object. The time primary-context object models temporal context in the form of creation date and last modification date. Quality of service is defined by the level of confidence in the accuracy of the captured data, the expected latency for retrieving the captured data, and the optional parameter, the expected duration that the data will be valid for. For dynamic, real-time environments, temporal context is important to categorise and choose relevant data.

Spatial objects may be combined with one another in the following way: a system object may contain other system objects, real world objects, and/or data objects; a real world object may contain other real world objects and/or data objects; a data object may contain other data objects. Possible combinations, as shown in Figure 3, are reflected in the PCM.

B. Primary-Context Ontology

iTransIT systems and pervasive transportation services require access to a thorough representation of domain knowledge: the concepts that exist in the domain and the relationships that hold between them, so that they can interpret and reason about context information. The PCOnt explicitly defines concepts and relationships, pertaining to the transportation domain, in terms of the Web Ontology Language (OWL). This attaches semantic meaning to the context information and enables it to be machine interpretable, as well as human readable.

The PCOnt consists of global ontologies that are common to all iTransIT systems, and system ontologies that are associated with a particular system area, in accordance with the sub-layers of the common spatial data layer. An example of a global ontology is the road network ontology, containing terms like 'motorway', 'road' and 'junction'. A car parking ontology is an example of a system ontology, which contains specific terms, such as 'car park', 'car parking space' and 'car park barrier'.

The root concepts of the PCOnt are spatial objects and primary-context, i.e. the OWL representation of the PCM. System objects, real world objects, and data objects are all formally defined, as well as location, identity, time, and quality of service primary-context. The relationships between spatial objects and primary-context are also explicitly outlined.

The type of a spatial object, classified by its identity primary-context object, must be a valid concept in the PCOnt. A concept is defined in terms of its relations to other concepts or datatypes. For example, consider the PCOnt extract depicted in Figure 4. The concept Bus is a subclass of Public Vehicle (and consequently also of Vehicle, Real World Object and Spatial Object), and is related to the Bus System concept through the property *hasBus*, the Route concept through the property *hasRoute*, and an integer datatype through the property *hasCapacity*. OWL also allows the addition of synonyms, such as bus/coach, tram/trolley, car/automobile.

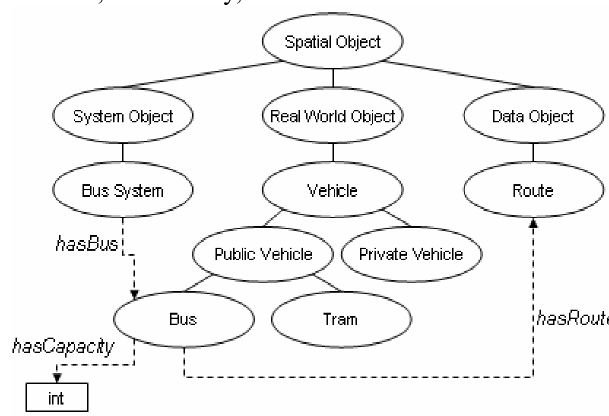

Figure 4. PCOnt extract

Through this common representation scheme, all parties in the iTransIT architecture have a shared understanding of the transportation concepts and, based on this, can correlate information, distributed throughout the common spatial data layer, or can infer new information using the innate reasoning mechanisms of OWL. Checking the consistency of context, and deducing high-level, implicit context from low-level, explicit context are considered the two main goals of reasoning [11]. Consistency checking could occur, for example, when a car park is modelled as a real object, without being associated with a location primary-context object, and submitted to an iTransIT system. The iTransIT system would then check the validity of the object against the ontology, discover its

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inconsistency, and declare it as incompatible with the iTransIT architecture. An example of high-level context-information deduction is as follows: if *contains* is defined as an *owl:TransitiveProperty*, car park system A *contains* car park B, and car park B *contains* car park space C, it can be deduced that car park system A *contains* car park space C.

```xml
<?xml version="1.0" encoding="UTF-8"?>
<primaryContextModelObject>
    <realWorldObject>
        <identityContext>
            <type>CarPark</type>
            <autoID>00012 </auto ID>
            <name>RCS car park </name>
            <description>Royal College of Surgeons Car Park </description>
        </identityContext>
        <locationContext>
            <openGISLocation>O 008 741</openGISLocation>
            <symbolicLocation> St. Stephens Green</symbolicLocation>
            <symbolicLocation> Dublin 2 </symbolicLocation>
        </locationContext>
        <data Object>
            <identityContext>
                <type> NumberOfFreeSpaces </type>
                <auto ID>00085</auto ID>
                <name> Number of spaces available in RCS</name>
            </IdentityContext>
            <time Context>
                <creationDate>2006-09-25T19:25Z</creationDate>
                <lastModificationDate>2006-09-25T19:25Z</lastModificationDate>
            </timeContext>
            <qualityOfServiceContext>
                <confidenceLevel> 80 </confidenceLevel>
                <retrievalLatency> 5 </retrievalLatency>
                <expectedLifetime> 40 </expectedLifetime>
            </qualityOfServiceContext>
                <parameter>
                    <name>NumberOfFreeSpaces</name>
                    <type>int</type>
                    <value>24</value>
                </parameter>
        </dataObject>
    </realWorldObject>
</primaryContextModelObject>
```

Figure 5. PCM object in the car park system, modelling a car park

V. Assessment

The feasibility of representing ITS in terms of the PCM and PCOnt has been assessed by modelling a pervasive transportation service scenario. The scenario involves a smart parking space locator service that dynamically pinpoints the nearest car park, with an available car parking space, to a user. The vehicle is then informed of the location of this car park and guides the user accordingly. This scenario demonstrates a combined approach to manage, define, and reason about context information, involving context models and ontologies.

The outlined scenario uses information provided by a car park system and a vehicle positioning system. Figure 5 demonstrates how such system information can be modelled using the PCM in the XML language. Some parameters have been omitted to allow for a more concise diagram. This object-oriented model is used to communicate information, based on primary-context, between systems and between systems and services. The PCOnt defines the valid object types and their structure.

Figure 6 shows an extract of the PCOnt used by the car park system, written in the Protégé tool. The PCM objects' structure is formalised through ontology restrictions, such as the existential restriction placed on the car park system object, stating that it must be associated with at least one car park real world object: *∃ contains CarPark*.

VI. Conclusions & Future Work

In order for pervasive transportation services to become a reality, a standard way to model context-information from heterogeneous ITS has to be established.

This paper presented a combined modelling approach, involving traditional context-modelling techniques, and ontologies. Distributed context-information is modelled using the PCM, which represents data based on its primary-context: location, identity, time and quality of service, allowing the information to be managed, stored, shared, and accessed in a scalable manner. The PCOnt provides a thorough representation of the transportation domain, enabling the correlation of data from independent sources and the deduction of high-level, implicit context from low-level, explicit context.

A smart parking space locator service has been modelled using the PCM, in terms of the PCOnt, in order to assess the feasibility of our combined approach. This scenario demonstrates that context information originating in distributed, autonomous sources can be represented using a common data model and structured following a common ontology, resulting in data that can be shared, associated, merged, or reasoned about.

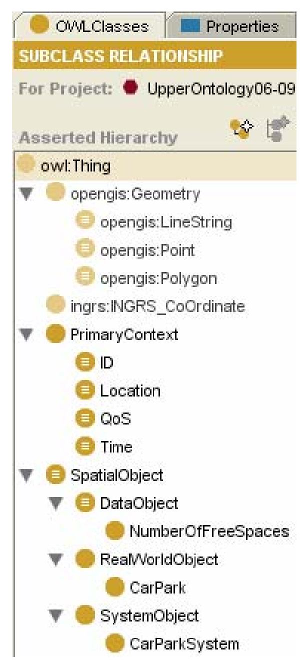

Figure 6. PCOnt extract used by the car park system

In future work, we intend to extend the PCOnt to include more sub-layers of iTransIT's common spatial data layer, and to create an entire proof-of-concept service that implements the PCM

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and PCOnt, to demonstrate all of their features and to evaluate their effectiveness.

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